X-ray Spectrometers on-board Aditya-L1 for solar flare studies

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Aditya-L1 mission will carry two high spectral resolution X-ray spectrometers to study solar flares. The soft X-ray spectrometer will cover energy range from 1 to 30 keV while that of hard X-ray spectrometer will be from 10 to 150 keV. These two instruments together will provide opportunities to study the plasma parameters during solar flares as well as acceleration mechanisms of energetic particles during the flaring time.

Keywords: Sun: Coronal Heating, Flares, CMEs; Detectors: SDDs, CdTe, CZT

1. Introduction

Solar Flares are first observed by Carrington and Hodgson in 1859 as brightening of few minutes on the solar atmosphere. Flares have then been observed in Hydrogen alpha line originating in chromosphere regularly. The complex nature of the structures like different source sizes, associated plasma ejections, and Morton waves, were reported. Radio observations during the flaring time indicated that flares not only heat the plasma but it also accelerates electrons which produce these radio emissions. In late 1950s when space observations were feasible, flares are well observed in X-ray energies. It has been realized from these observations that a sizeable portion of the flare energy is emitted in Hard X-rays. Gamma-ray emissions are also seen during solar flares making it a phenomenon observed in all wavebands (Figure 1). It is now understood that although the flaring phenomenon is initiated in the corona, energy is deposited by the flare in all layers of the solar atmosphere (corona, chromosphere, and photosphere).

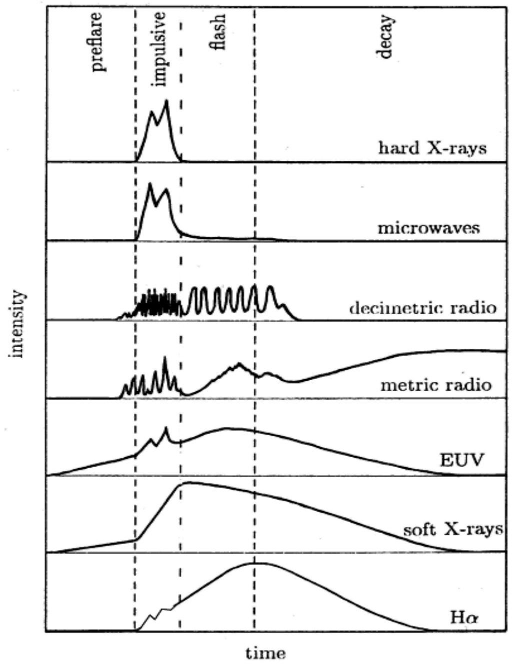

Figure 1: Typical flare brightening at different wavelengths [1].

Though solar flares are observed in all energy bands, X-ray energies provide the best observations due to high temperatures generated during the flares. Solar flares are classified (as A, B, C, M, and X) by their brightening in the soft X-ray band with the X-class flare having an energy range of 10^{-4} Wm^{-2} (X1) to 10^{-3} Wm^{-2} (X10) with M1 flux smaller by an order to X1 flux and so on.

Two solar spectrometers covering soft (1–30 keV) and Hard (10-150 keV) X-ray bands will be flown on Aditya-L1 mission to study solar flares and its dynamics.

2. Overall Science Objectives

The two X-ray spectrometers covering the Energy band from 1 to 150 keV will allow us to carry out the following science objectives: (i) Study of heating mechanisms during the

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flare [2], (ii) Quantitative measure of flare energies by measuring the temperature of the plasma (thermal energy) and also studying the acceleration of particles (non-thermal energy) [2], (iii) Coronal abundance during the flare evolution [3], (iv) pre-cursor phase activities possibly related to reconnection mechanisms [4], (v) time variation of spectral parameters as well as quasi-periodic oscillations especially seen in hard X-ray energy [5], (vi) Association of flare and CMEs [6], and (vii) Prominence eruption and the flare trigger [7].

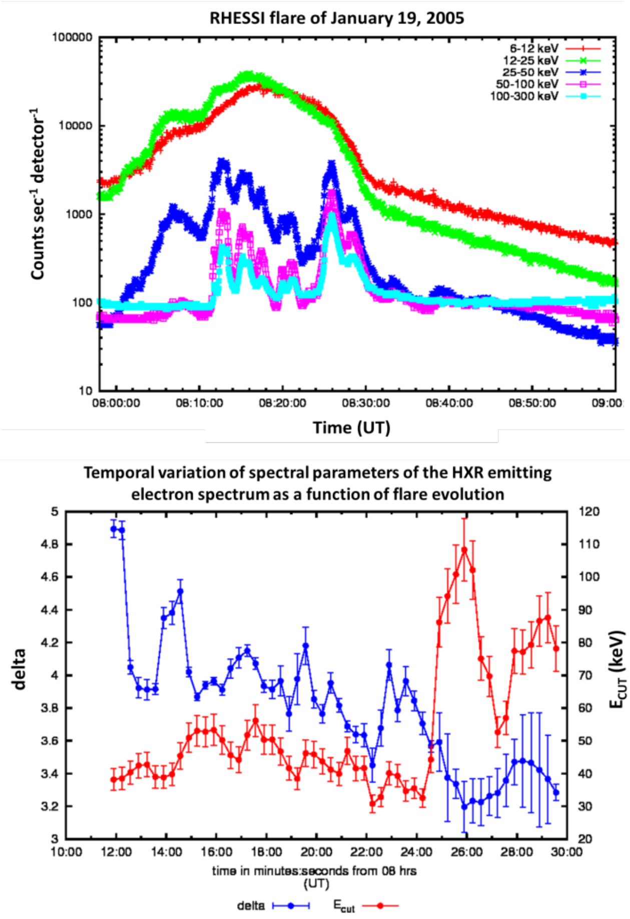

Figure 2: (top) Light curve of X1 class flare of Jan 19, 2005 showing pulsations during the impulsive phase; (bottom) temporal variation of low-energy cut-off of the HXR emitting electron distribution and its spectral index.

A typical X1 class flare and the spectral parameters of the HXR emitting electrons [8], are studied and plotted in Figure 2, as the flare evolves over time.

3. Solar Low Energy X-ray Spectrometer (SoLEXS)

SoLEXS will cover the energy band from 1 to 30 keV with a spectral resolution of <4% (i.e. < 250 eV at 6 keV). This energy band will help in obtaining the thermal energy of the flares. To cover the large class of flares, from A – to X – class, SoLEXS carry two identical detectors with different apertures. The large area aperture will cater to small flares (A – to C – class), while the small aperture will observe intense flares (> C class).

SoLEXS is configured as two packages, viz. Detector package and Electronics package. The detector package carries the two detectors and its associated High Voltage power supply along with sensitive preamplifiers. Electronics package carries the required processing and power electronics to cater to the instrument.

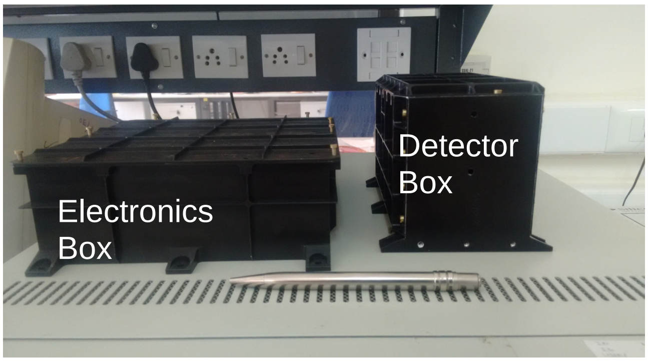

Figure 3: SoLEXS Engineering Model.

SoLEXS will also carry an on-board calibration source for the gain calibration over time to obtain high spectral quality for its data. With its on-board processing, SoLEXS will provide spectra with 1 sec cadence during flare. A flare trigger using the count rate threshold is implemented to operate this instrument in quiet as well as flare mode. This flare trigger is also provided as a hardware line to SUIT instrument on-board Aditya-L1. Currently, SoLEXS' Engineering Model (both the packages) is being integrated to test for its performance [9].

4. High Energy L1 Orbiting X-ray Spectrometer (HEL1OS):

HEL1OS is a high energy X-ray spectrometer (10 keV to 150 keV) for studying the impulsive phase of solar flares. HEL1OS aims to take advantage of the spacecraft's location at Sun-Earth L1 in order to obtain uninterrupted observations of the short lived impulsive phase of solar flares. This energy band helps us to identify the non-thermal energy release during the flares.

Figure 4: Engineering Model of the HEL1OS payload.

HEL1OS is being developed [10] with two different types of detectors, CZT and CdTe; the CZT detector is a state-of-the-art, near room temperature device and in order to achieve a total geometric area of 32 cm^2, two such detectors (16 cm^2 per detector) are used to cover the energy range 20 keV to 150 keV and operates in the temperature range of 5 to 20 ^{0}C. The individual detectors are pixelated with 256 pixels, with pixel dimension 2.46 mm x 2.46 mm. The CdTe detector, which has better energy resolution at lower energies, is used for detailed spectroscopic studies from 10 keV to 40 keV and operates in the temperature range of -35 to -25 ^{0}C. The overall geometric area of 0.5 cm^2 will be achieved by using 2 CdTe detectors, each with area 0.25 cm^2. The field-of-view of the instrument has been constrained to 6^0 x 6^0 by using a stainless steel (SS) mesh type collimator.

At present, the Engineering Model (EM) of HEL1OS (Figure 4) is under development. All electronics cards (Front-end Electronics with detectors mounted, Processing Electronics and Power Conditioning Electronics) are fabricated and populated, with electrical testing and performance verification with detectors is underway.

5. Summary:

Solar Flares in X-ray have been studied in detail with the RHESSI mission for the last several years albeit with low spectral resolution. The X-ray instruments on-board Aditya-L1 will provide a large energy coverage (1 to 150 keV) with a spectral resolution better than of RHESSI providing opportunities to study coronal abundances, break energy shift for different class of flares, separation of thermal and non-thermal energies etc. These two instruments will also carry out Flare-CME studies in combination with Coronagraph and also Prominence-Flare-CME relations with SUIT and Coronagraph. Aditya-L1 being at Sun-Earth L1 point, provides us with a unique opportunity to study the flare phenomenon continuously in X-rays without any data gap like in other previous missions.

6. References:

1. Benz, Flare Observations, Living Rev. Sol. Phys., 2017, 14:2, 1-59
2. Hannah et al, Microflares and the statistics of X-ray Flares, Space Sci. Rev., 2011, 159, 263-300
3. Narendranath et al., Elemental Abundances in the Solar Corona as Measured by the X-ray Solar Monitor onboard Chandrayaan-1, Sol. Phys., 2014, 289, 1585-1595
4. Joshi et al., Pre-flare activity and Magnetic reconnection during the evolutionary stages of energy release in a solar eruptive flare, ApJ, 2011, 743, 195-208

5. Rao et al., RT-2 Detection of Quasi-Periodic Pulsations in the 2009 July 5 Solar Hard X-ray Flare, ApJ, 714, 1142-1148.
6. Yashiro et al., Spatial Relationship between Solar Flares and Coronal Mass Ejections, ApJ, 2008, 673, 1174-1180
7. Chifor et al., The early phases of a solar prominence eruption and associated flare: a multi-wavelength analysis, A&A, 458, 965-973
8. Warmuth et al., Rapid changes of electron acceleration characteristics at the end of the Impulsive Phase of an X-class Solar Flare, ApJ, 2009, 699, 917
9. SoLEXS Team, SoLEXS PDR Document; ISRO-ISACADITYA-L1-RR-1343, 2016
10. HEL1OS Team, HEL1OS PDR Document; ISRO-ISAC-ADITYA-L1-RR-1342, 2016